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# Parametric animacy percept evoked by a single moving dot mimicking natural stimuli

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Identifying moving things in the environment is a priority for animals as these could be prey, enemies or mates. When the shape of a moving object is hard to see, motion becomes an important cue to distinguish animate from inanimate things. We report a new stimulus in which a single moving dot evokes a reasonably strong percept of animacy by mimicking the motion of naturally occurring stimuli, with minimal context information. Stimulus movements are controlled by an equation such that changes in a single movement parameter lead to gradual changes in animacy judgments with minimal changes in low-level stimulus properties. An infinite number of stimuli can be created between the animate and inanimate extremes. A series of experiments confirm the strength of the percept and show that observers tend to follow the stimulus with their eye gaze. However, eye movements are not necessary for perceptual judgments, as forced fixation on the display centre only slightly reduces the amplitude of percept changes. Withdrawing attentional resources from the animacy judgment using a simultaneous secondary task further reduces percept amplitudes without abolishing them. This stimulus could open new avenues for the principled study of animacy judgments based on object motion only.

**Keywords:** Perception of animacy; social cognition; biological motion; motion perception.

## Introduction

For many species, distinguishing animals from other things in the environment is essential, as those animals could be prey, predators or mates. One characteristic of animals that sets them apart from plants, fungi and non-living things is animate motion. The distinction between animate and inanimate things appears early in infancy (Gelman, 1995; Opfer, 2002), is cross-culturally uniform, and is related to the distinction between agents and non-agents (Premack, 1990), and between entities capable of intentionality or not (Brentano, 1970). The distinction has important consequences on behaviour, for example: the cognitive strategies that humans use to explain and predict the movements of moving objects change depending on whether they think the moving object is animate or not (Dennett, 1978; Leslie, 1994). Observers automatically attempt to explain and predict the movements of inanimate things using folk physics, an intuitive understanding of physics. By contrast, observers spontaneously resort to attributing mental states to things they consider animate in order to explain and predict their movements, i.e. they use

folk psychology or theory-of-mind. The importance of this dichotomy is also reflected in the organization of the ventral temporal cortex of humans and monkeys, where animacy appears to be a basic distinction in the hierarchical organization of object representations and semantic categories in the human brain (Caramazza & Shelton, 1998; Hanson, Matsuka, & Haxby, 2004; Kiani, Esteky, Mirpour, & Tanaka, 2007; Kriegeskorte et al., 2008; Mahon & Caramazza, 2009). Recent evidence similarly shows a categorical response to animals in the right amygdala (Mormann et al., 2011). The fact that animate / inanimate is a basic grammatical distinction in some languages shows that humans have long been aware of the fundamental nature of this dichotomy (Brown & Ogilvie, 2008).

Although the motion of an object might not always suffice to decide whether something is animate or not (Gelman, Durgin & Kaufman, 1995), motion is one of the key characteristics of animate things, and thus, being able to use motion to detect them would be of evolutionary advantage (Barrett, Todd, Miller, & Blythe, 2005). This is particularly important when shape information is poor, due to distance, low visibility or lack of visual focus. Further,

moving things are salient and can force an observer to react when they are looming towards him. Evidence that animals use motion to detect other agents can be found for example in airborne predators: Hunting dragonflies use motion camouflage to appear stationary to the prey they attack (Mizutani, Chahl, & Srinivasan, 2003). Given that humans use different cognitive strategies to predict the motion of animates and inanimates, distinguishing these categories as early as possible could help to react better faster.

In a classic study, Heider and Simmel (1944) have demonstrated that very simple displays of moving interacting shapes can evoke attributions of mental states. Since then, many factors leading to attributions of animacy to simple moving shapes have been described, as reviewed for example by Gao and Scholl (2011): “sudden direction and speed change, synchronized motions, rational interactions with spatial contexts and other objects, apparent violations of Newtonian mechanics, and multiple objects’ coordinated orientations”. Of particular importance are cues that make the object’s movements appear goal-directed (Opfer, 2002) or more generally all cues leading to the attribution of intentionality to the object (Tremoulet & Feldman, 2006).

Everyday experiences suggest that we can identify animals only from their motion in space, even when they do not display form information, articulated motion, interaction with other agents or objects, clear goal-directed action or intention. Indeed, insects flying or scurrying around (for example, fireflies at night) can be perceived as animate beings because they appear self-propelled, i.e. they appear to move by themselves, without influence of an external force (Bingham, Schmidt, & Rosenblum, 1995; Gyulai, 2004; Scholl & Tremoulet, 2000; Stewart, 1982; Szego & Rutherford, 2007; Tremoulet & Feldman, 2000). While convincing stimuli to display biological motion that clearly evoke naturally-occurring stimuli do exist (namely point-light walkers), we believe that no comparable single-dot stimulus has been reported that can evoke natural stimuli without resorting to form information, using multiple interacting objects, or a strong context given prior to stimulus presentation.

The aim of the present study was to develop a stimulus capable of evoking a reasonably strong percept of animacy in as many participants as possible, without any influence from the object’s form, its interactions with the environment or a strong context information. An important aspect was that observing the stimulus should engage processes normally involved in making animacy decisions about natural moving objects. Thus, the stimulus, although artificial, should tap into representations of animate and inanimate moving objects known to humans. We manipulated the impression of self-propelledness evoked by a single moving dot to induce a gradual variation in the percept of animacy, using a parametric design. Parametric approaches achieve a great amount of experimental control across conditions, because only the dimensional level of a single experimental variable changes across conditions, which constrains the

response pattern (Sternberg, 1969; Weiner, Freedheim, Schinka, & Velicer, 2003). We therefore used a parametric approach here: a movement equation in which a single parameter controlled the impression of self-propelledness of the object, while keeping as many low-level stimulus characteristics as constant as possible.

In a series of behavioural experiments, we aimed to show that this stimulus evokes a consistent and convincing percept of animacy with very minimal instructions for the participant, and that this percept varies according to changes of the parameter controlling the object’s movements. Further, we tested whether participants need to be free to perform eye movements for the percept to be evoked, and whether full and constant attention on the stimulus is necessary to perform perceptual decisions about it. This paper reports 6 experiments: Experiments 1-3 demonstrate the consistency of the percept, Experiment 4 describes gaze behaviour, Experiment 5 show what happens when gaze behaviour is inhibited, and Experiment 6 report percepts obtained when participants were forced to perform a second task simultaneously with the animacy judgment. While each experiment is described separately, sections pertaining to all experiments are not repeated. The results of Experiments 4, 5 and 6 are presented together for direct comparison.

## Experiment 1: Animacy judgments about extreme stimuli

This experiment served to compare the percepts evoked by the most animate and the most inanimate of our stimuli. These represent the extremes of our parametric stimulus continuum.

## Methods

### Participants

56 participants (27 female), mean age 26.4 years (21 to 36 years) from the Tübingen community volunteered as participants for 8 Euro per hour. All participants were naïve as to the design of the experiment and the manipulations occurring with the stimuli. All participants provided informed written consent.

### Stimuli

In this study, we aimed to create a stimulus that evoked percepts of animacy only through the way it moved. To make sure that all cues about animacy were contained in its motion, we opted for the simplest object possible (a dot) so neither shape nor orientation could influence percept. Our stimulus thus consisted of a single moving white dot (size: 0.2°) moving on a black background. The dot’s position

was updated at every screen refresh (60 Hz) according to movement trajectories computed at the start of each run by a set of two movement equations (see below).

What parameters of the object's motion should we manipulate in order to engage perceptual processes involved in real-world judgments of animacy? Simple motion cues can already influence animacy percepts: a high average speed, high acceleration and movement directions other than towards the bottom of the screen have been associated with increased animacy ratings (Gyulai, 2004; Szego & Rutherford, 2007; 2008a; Tremoulet & Feldman, 2000). However, using differences in average speed to influence animacy judgments can transform an animacy-judgment task into an indirect speed-judgment task (Szego & Rutherford, 2008b). Such a task is likely to mainly engage cognitive processes that are unspecific to animacy perception. Also, we aimed at creating realistic motion trajectories more complex than a straight line and constant speed, to yield a stronger animacy percept in which observers would need to integrate information contained in the motion over time.

We decided to use artificial stimuli for the following reasons: First, this makes it much easier to create parametrically controllable stimuli, which is necessary to induce variations in the animacy percept that follow a classic psychometric function. Second, this method allowed tight control of the trajectory and motion characteristics. Third, the method allowed generation of an unlimited number of different stimuli, thus avoiding learning and recognition of particular trajectories.

We designed our stimuli to mimic simple objects that can easily be categorized into animate and inanimate simply on the basis of their motion (Leslie, 1982), namely a fly (animate) and a leaf drifting in the wind (inanimate). We simulated the fly by making the object appear self-propelled (and thus, animate; see Introduction), and simulated the leaf drifting in the wind by making the object appear to be submitted to an external force (thus making it appear inanimate). To do so, we relied on our intuition, as follows. We attempted to simulate the exploratory flight of an insect using trajectories with seemingly random, yet rather smooth changes in motion direction. This was implemented as a sum of two sine waves of different frequencies ( $\sigma_1$  and  $\sigma_2$ ; see details below) plus smoothed gaussian noise ( $\eta$ ), which together determined the motion direction over time. The phase values of the sine waves were initialized to different random values for each trial, which ensured different starting movement directions on each trial. The effects of wind on a light, flying object were implemented by sudden accelerations with a constant direction ( $W_a$ ) and a particular temporal profile ( $W_s$ ). Both insect-like and wind-like motion effects were added together to create the final stimuli. By changing the weighting of these effects, we could make the dot appear to move more like the leaf drifting in

the wind, or the fly. This weighting was done by one parameter ( $\beta$ ), which determined the relative influence of several aspects of the two effects (see details below and Figure 1 for examples). At  $\beta = 0$ , changes in movement angle contained minimal sinusoidal changes, and were driven by the more abrupt and less regular wind effects accompanied by large changes in object speed. In contrast, with  $\beta = 1$ , there was almost no wind effect, but sinusoidal changes in movement angle with both high and low temporal frequencies were strongly present.

In order to obtain the desired percepts (both the fly and the leaf-in-the-wind), we adjusted the frequencies of the sine waves, the kind and scale of the noise, the magnitude and temporal profile of acceleration for the wind and all other aspects of the movement equation. This adjustment was iteratively repeated and tested in pre-experiments until the moving object appeared self-propelled or externally moved to us and to several colleagues. It is worth noting that our stimuli were not created with the aim of exactly replicating real fly or leaf movements, but only to yield perceptual approximations. Once we were satisfied with the stimuli obtained, we systematically investigated, in the experiments reported in the present paper, how convincing these stimuli were to uninformed participants.

Our equation was made of two parts, each describing changes over time. The first part of the equation described how the direction of the dot's motion changed over time relative to a reference direction on the computer screen (vertical down). The second part of the equation described how the speed of the dot changed over time.

**Direction** =  $\sigma_1 * (\beta * 1.22 + 0.61) + \sigma_2 * (\beta * 1.22 + 0.61) + \eta * (\beta * 0.01 + 0.002) + (W_a * (1.1 - \beta) * \pi / 180)$ . Unit: radian.

**Speed** =  $\mu + W_s * (1.1 - \beta)$ , normalized to range: [2.95 10.33]. Unit: degrees of visual angle per second.

Movement direction is given in radians (ranging from 0 to  $2\pi$  rad; 0 = vertical down), and speed in degrees of visual angle per second or deg/s. Parameters  $\sigma_1$ ,  $\sigma_2$ ,  $\eta$ ,  $\mu$ ,  $W_a$  and  $W_s$  are time-series. Parameter  $\beta$  ranged from 0 to 1, was constant during one stimulus and was the key independent variable in the experiment. The variables  $\sigma_1$  and  $\sigma_2$  were sine waves with frequencies of 0.3 Hz and 0.57 Hz respectively.  $\eta$  was gaussian noise (mean 0, std 2.77 rad) smoothed using a moving average over 0.5 s.  $\mu$  was 5.9 deg/s.  $W$ , composed of  $W_a$  (movement angle) and  $W_s$  (speed), stands for bursts of wind. It was used to evoke the impression of an external force acting on the moving object.  $W_s$  consisted in linearly increasing acceleration for 0.17 s up to 11.8 deg/s, then linearly increasing deceleration (at  $1/10^{\text{th}}$  of the intensity of acceleration) for 0.17 s, then constant deceleration until pre-wind speed for 0.72 s.  $W_a$ , the direction of the wind, was random within a window of  $\pm 1.05$  rad from vertical up. Bursts of wind occurred

7 times at random intervals during the animation and could be overlapping in time. The speed time-series were normalized to the range of 2.95 to 10.33 deg/s. Coordinates were calculated by projecting speed magnitude values on X and Y axes according to the speed angle values, then integrating over time. All computations were implemented in pixels/frame, and final coordinates were rounded to the nearest integer. There was no intended or observed systematic relation between the speed of the dot and the curvature of its trajectory (2/3 power law; see Viviani & Stucchi, 1992). We aimed to keep as many low-level stimulus characteristics of the stimuli as similar as possible, but some changes were necessary: vertical positions on the screen, mean acceleration, movement directions and overall aspect of the trajectory were very similar, while horizontal positions and the profile of speed and acceleration changed (see more detailed analysis in Experiment 2). Stimuli were created and displayed using MATLAB R2010A (The MathWorks, Natick, MA) with the Psychtoolbox extensions (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997).

~ Please insert Figure 1 about here ~

### Apparatus and procedure

Stimuli were presented at a distance of 60 cm on a 23-inch TFT Screen with a screen resolution of 1920 by 1200 and a refresh rate of 60 Hz. Only stimuli from the most “inanimate” and the most “animate” ends of our stimulus continuum were used in Experiment 1 ( $\beta$  values: 0 and 1). 30 stimuli of each type were presented in a randomized order different for each participant. Each stimulus lasted for 3.3 s. The participants’ task was a yes-no decision task with the following instructions: “Imagine you are looking through a window at objects moving outside. Half of them are animate, half of them are not. Both are shown as a white dot, but they differ by their movement. Please decide for each object whether it’s animate or not.” Participants were asked to respond by pressing one of two designated buttons on a computer keyboard with their right hand as soon as the stimulus disappeared (buttons were counterbalanced across participants). Response times were collected only from the last 28 participants due to problems with the experiment setup. After the end of the experiment, we debriefed the participants by asking them: “How did you decide if the object was animate or not?”. The statements of the last 13 participants were recorded in writing and are reported in Appendix A.

### Analysis

Animacy judgments given to ‘fly’ and ‘leaf’ stimuli and response times were compared using 2-tailed paired-samples t-tests. Individual animacy judgments (proportion “animate” responses) for the ‘fly’ and the ‘leaf’ stimuli were

compared using Chi-squared tests to determine how many participants rated the ‘fly’ as more animate than the ‘leaf’. All tests reported in all experiments were implemented in MATLAB R2010A unless otherwise stated.

## Results

As shown in Figure 2, our group of participants judged the ‘fly’ stimuli as more animate than the ‘leaf’ stimuli ( $t(55)=6.53$ ,  $p<<0.001$ ). The same effect could be found in 38 of 56 individual participants (69% of all participants). In addition, 5 participants (9%) unexpectedly rated the ‘leaf’ stimulus as significantly more animate than the ‘fly’ stimulus. Response times did not differ between stimulus conditions (mean=1280ms, SEM=162ms,  $t(28)=0.84$ ,  $p>0.4$ ). The verbal reports obtained during the post-experiment questionnaire (see Appendix A) reveal that participants spontaneously thought about flying insects (animate) or passively moved objects (inanimate) when making their animacy judgments.

~ Please insert Figure 2 about here ~

## Discussion

The results of this experiment show that for most naive participants, the ‘fly’ stimulus appeared more animate than the ‘leaf’ stimulus. Unexpectedly, some participants (9%) reported the opposite percept: to them the ‘fly’ stimulus appeared less animate than the ‘leaf’ stimulus. This will be discussed in detail in the general discussion. The verbal reports obtained during the post-experiment debriefing (Appendix A) revealed that many participants spontaneously thought that objects could be animate when they moved in a way reminiscent of a flying insect which moved by itself, whereas they considered objects to be not animate when they appeared to move as if propelled by an external force, for example a leaf blown by the wind. This confirmed that our intentions in creating the stimuli were recognized in the stimuli by many participants even though we did not tell them anything about self-propelledness, insects, leaves or wind. This suggests that we succeeded in evoking the movements of animate and inanimate moving objects through the motion of a single dot, at least for most participants.



## Experiment 2: Animacy judgments about parametric stimuli

The goal of this experiment was to assess whether gradual changes in the parameter controlling the object's motion could lead to graded changes in animacy judgments.

### Methods

#### Participants

Participants were the same as in Experiment 1. They performed Experiment 2 after Experiment 1, on the same day. They were still naive as to the goal and design of the experiment.

#### Stimuli and procedure

Stimuli used were identical to Experiment 1, except that parametric stimuli were created using the following six  $\beta$  values: 0, 0.2, 0.4, 0.6, 0.8 and 1. These values will be referred to as "morph levels". Statistics of stimulus characteristics are shown in Figure 3. Apparatus and procedure were identical to Experiment 1.

As can be seen in Figure 3, the characteristics of the stimuli were very similar across morph levels but not completely identical. We collected stimulus characteristics from all participants, trials and time points in these trials and sampled 100 values per morph level from the data for testing (note: the following results were robust across samples). Friedman tests (ANOVA tests were not used on stimulus characteristics data as residuals deviated significantly from the normal distribution) revealed that acceleration and direction did not change with stimulus condition (Chi-square statistic (5,495)<5.5,  $p>0.37$ ). However, horizontal and vertical position as well as speed did change with stimulus condition (Horizontal position: Chi-square (5,495)=74.9,  $p<0.001$ ; vertical position: Chi-square (5,495)=398.5,  $p<0.001$ ; speed: Chi-square (5,495)=98.5,  $p<0.001$ ). The profile of these changes was different from the observed changes in percept and could thus not explain the animacy judgments (see Results).

~ Please insert Figure 3 about here ~

### Analysis

Animacy judgments given to the six different stimulus types were averaged across trials and analysed using two methods. First, a one-way, repeated-measures ANOVA was computed on the data with morph level as independent variable (six values) using the PASW 18.0 software (SPSS Inc., Chicago, IL). Second, the data were fitted with a psychometric function using morph level as independent variable (a cumulative gaussian function was used, fitted using the Levenberg-Marquardt algorithm implemented in MATLAB). The fits were performed on group-averaged data as well as individual datasets to assess group effects and to determine how many participants gave judgments that could be significantly explained by a fitted psychometric function. Results of these individual tests were compared to results of Experiment 1 as the same participants performed both experiments. Similarities between changes in the low-level stimulus characteristics and the changes in percept were compared using non-parametric tests. Response times were again collected from 28 participants and analyzed using a one-way, repeated-measures ANOVA with morph level as independent variable (six values).

### Results

Results are shown in Figure 4. As expected, a one-way, repeated-measures ANOVA revealed a very strong effect of morph level on the animacy percept ( $F(5,275)=26.85$ ,  $p<0.001$ ). Linear, quadratic and cubic trends were found:  $F(1,55)=37.61$ ,  $p<0.001$ ;  $F(1,55)=5.57$ ,  $p<0.03$ ;  $F(1,55)=4.31$ ,  $p<0.05$  respectively. To assess the consistency of our effects within our group of participants, we attempted to fit individual data with a psychometric function (cumulative gaussian) and test whether the fitted function could significantly explain the variation in the judgments (linear regression,  $p<0.05$ ). The results revealed that the data of 41 out of 56 participants could be significantly explained with a fitted cumulative gaussian function. Of these 41 participants, 6 showed percepts opposite to those expected (i.e.: the 'leaf' was rated as more animate than the 'fly' stimulus). The remaining 35 participants had a mean Point of Subjective Equality (PSE) of 45% (SEM = 2.4%) of the morph level range and a mean Just Noticeable Difference (JND) of 26% (SEM = 4.3%). Agreement with the results of Experiment 1 on the extremes-only stimuli was very high: 38 participants had significant results in both experiments. The five participants which unexpectedly showed the opposite percept in Experiment 1 ('leaf' rated as more animate) again showed responses opposite to those of the other participants in the current experiment. Re-

sponse times did not differ between stimulus conditions (mean=1150ms, SEM=127ms,  $F(5,140)=0.19$ ,  $p>0.96$ ).

Some physical characteristics of our stimuli also changed across conditions (see Methods and Figure 3). However, these changes had a different profile over morph levels than the changes in animacy judgments (see Methods): Horizontal position and speed of the stimuli peaked at M4 and M5 respectively where they were higher than at 'fly' (Mann-Whitney U test: position:  $U=3.43$ ,  $p<0.001$ ; speed:  $U=1.73$ ,  $p=0.0416$ ). These data were not different at M3 than at 'fly' (position:  $U=0.71$ ,  $p>0.24$ ; speed:  $U=-0.16$ ,  $p>0.43$ ). By contrast, animacy judgments were higher at 'fly' than at M3 and lower morph levels but no difference was found between 'fly' and M5 (Tukey-Kramer post-hoc tests).

~ Please insert Figure 4 about here ~

## Discussion

The results of this experiment show that the desired parametric changes in animacy judgments could indeed be evoked by changes of our motion parameter  $\beta$  in our group of participants as well as in about 70% of individual participants. Further, the comparison with the results of Experiment 1 shows that our stimuli work not only for extreme but also for intermediate values of our parameter  $\beta$ , without unexpected perceptual effects occurring in the stimulus continuum. Finally, although some low-level stimulus characteristics do change as a function of the parameter  $\beta$ , the profile of these changes are quite different from the changes in percept. It is thus very unlikely that the observed changes in animacy judgments are due to changes in average stimulus position or speed, which suggests that participants relied on more high-level properties to solve the task such as integration of the motion over time to detect signs of self-propelled motion, as desired by the experimenters.

## Experiment 3: Verbal descriptions of parametric stimuli

The goal of this experiment was to replicate the gradual changes in percept as a function of morph level obtained in Experiment 2, but by having participants report their percept using a different, less constrained method. The aim was to confirm the strength of the percepts evoked by our stimuli and exclude problems due to the forced nature of the responses obtained in Experiments 1 and 2.

## Methods

### Participants

14 participants (4 male), mean age 22 years (18 to 25 years) from the Tübingen community volunteered as participants for 8 Euro per hour. All participants were naïve as to the design of the experiment and the manipulations occurring with the stimuli. All participants provided informed written consent. This group of participants participated in Experiments 3, 4, 5 and 6, all on the same day, and the order in which these experiments were performed was counterbalanced across participants.

### Stimuli, apparatus and procedure

Stimuli and apparatus were identical to Experiment 2. The procedure was also identical to Experiment 2, except that participants had to give short written descriptions of what they thought the moving object they were presented with could be. The instructions were: "Imagine you're looking through a window at objects moving outside. Half of them are animate, half of them are not. Both are shown as a white dot, but they differ by their movement. Please describe each object in one sentence." One description sentence was collected per participant and per trial.

### Analysis

After the last experiment (Note: the same participants performed experiments 3, 4, 5 and 6), the participants were presented with the response sentences after these had been randomized and stripped of the trial labels. Each participant rated the sentences of another, randomly chosen participant. Instructions for the rating were as follows: "please rate how animate the object described in the sentence is, using values between 1 (clearly inanimate object) and 7 (clearly animate object)". For each condition and participant, the mean and median rating across trials were calculated. As means and medians were very similar (correlation between means and medians across participants and conditions was  $r=0.85$ ,  $p<<0.001$ ), means were used for further tests. As the data did not show indications of unequal variance across conditions (see Figure 5), a 1-way, repeated measures ANOVA was used to assess whether the mean ratings differed across conditions. The validity of the use of the ANOVA was confirmed by the fact that the residuals of the ANOVA were normally distributed (Kolmogorov-Smirnov test, comparing residuals against the normal distribution: KS statistic = 0.12,  $p>0.14$ ).

## Results

Ratings given to the verbal reports are shown in Figure 5. Ratings mostly lay in the upper half of the response range, suggesting that participants tended to describe most stimuli as animate. Nevertheless, results show that stimuli appeared increasingly animate when parametrically morphed from ‘leaf’ to ‘fly’: a 1-way, two-tailed repeated-measures ANOVA test revealed a highly significant effect of stimulus type on the group ratings ( $F(5,65)=5.26$ ,  $p<0.001$ ). No significant trends were found. No participants showed percepts opposite to those expected. Note: comparable Friedman tests on the means and the medians were also highly significant. Example responses are reported in Appendix B.

~ Please insert Figure 5 about here ~

## Discussion

These results show that the parametric changes in the percept of animacy evoked by our stimuli can be revealed even in free verbal descriptions given by naive observers. Although the changes in percept obtained using this method are smaller and less gradual than those obtained using the yes-no task in Experiments 1 and 2, these findings underline the strength of the percepts evoked by our stimuli.

## Experiment 4: What eye movements do participants make?

The purpose of this experiment was to determine where participants look when making animacy decisions about our stimulus. Given that only a single dot was present on the screen, our assumption was that participants would generally tend to follow the stimulus with their eyes. Our aim was to verify this hypothesis and to find out whether gaze behaviour would change depending on morph levels, stimulus characteristics and perceived animacy.

## Methods

### Participants

Participants were the same as in Experiment 3. They were still naive as to the goal and design of the experiment. The data of 2 participants had to be excluded due to technical problems with the eye tracker.

### Stimuli and procedure

Stimuli, procedure and setup were identical to Experiment 2. In addition, eye movements were recorded using a FaceLab eye tracker (Seeing Machines Inc., Tucson, USA). This 60 Hz infrared, camera-based system has an accuracy of about  $1.0^\circ$ , and was calibrated using nine reference points at the beginning of each recording session; subsequent calibrations within the session were performed as needed.

### Analysis

Eye tracking data were recorded as x- and y-pixel coordinates of point of regard on the screen during each trial. Recording started at the beginning of the trial and stopped with the participant's response. Custom software written in MATLAB was used to analyse the data. After removing eye blink data, distances between subsequent data points and eye movement speeds were calculated and converted to degrees of visual angle. Saccades were identified as a minimum of two subsequent sample points with eye movement speed exceeding  $30^\circ/\text{s}$ . Minimum interval between saccades was set at 0.2s. After counting the number of saccades per trial, data points acquired during and 0.1s after each saccade were removed from further analysis. Number of saccades per trial were collected and compared across conditions using a Friedman test (ANOVA tests were not used as residuals deviated significantly from the normal distribution).

To compare the acquired gaze paths to the stimulus paths, we computed gaze-to-stimulus distances between the coordinates of point of gaze and the stimulus position for each time point, trial and participant. To assess whether these distances were smaller than would be expected by chance, we compared the measured data to a control distribution by calculating the distance between the gaze path acquired in a given trial and the stimulus paths of all the other trials. We then assessed whether gaze-to-stimulus distances changed across conditions using a Friedman test (ANOVA tests were not used as residuals deviated significantly from the normal distribution). To identify which factors influenced the gaze-to-stimulus distance, we ran linear regression tests using dot speed, stimulus condition and participant response as explanatory variables. We calculated the linear regressions based on each of the three explanatory variables alone as well as the multiple regression based on all three explanatory variables together. Their explanatory power was compared using the adjusted R-squared statistic.

To test whether participants followed the stimulus with their gaze, we calculated the lag between gaze and stimulus paths, as follows. For each trial and participant, we calculated the cross-correlation between the positions of gaze and stimulus separately for X and Y dimensions, constraining the lag values between -1 and +1s, and collected the lag value at which the highest positive correlation between gaze and stimulus was found. Here again, we calculated a con-



trol distribution of lags by repeating the calculation after pairing the gaze path of each trial with the stimulus paths of all the other trials. A Friedman test was used to compare lag values across conditions (ANOVA tests were not used as residuals deviated significantly from the normal distribution).

Analysis of the perceptual judgments was the same as for Experiment 2.

## Results

### Percept

As expected, a one-way, repeated-measures ANOVA revealed a strong effect of morph level on the animacy percept ( $F(5,60)=14.32$ ,  $p<0.001$ ). Linear and cubic trends were found:  $F(1,12)=31.1$ ,  $p<0.001$ ;  $F(1,12)=8.7$ ,  $p<0.02$  respectively. The data of 9 out of 13 participants could be significantly explained with a fitted cumulative gaussian function. No participants showed percepts opposite to those expected. Response times did not differ between stimulus conditions (mean=1215ms, SEM=63ms,  $F(5,60)=0.8$ ,  $p>0.5$ ). These data are presented together with the data of Experiments 5 and 6 in Figures 7 (percept) and 8 (response times), and results are compared across these experiments in the Results section of Experiment 6.

### Saccades

The number of saccades per trial was low but quite variable across participants (mean and standard deviation of numbers of saccades/trial:  $0.93 \pm 1.15$ ). A Friedman test revealed no effect of Stimulus Condition on number of saccades per trial (Chi-square (5,60)=7.24,  $p>0.2$ ).

### Gaze paths

Inspection of the gaze path data and comparison to the stimulus paths suggested that participants tended to follow the stimulus with their eyes. 80% of all measured gaze positions were less than  $2.9^\circ$  away from the stimulus positions (median:  $2.13^\circ$ , quartile deviation:  $0.28^\circ$ ). These gaze-to-stimulus distances were much smaller than control values obtained after randomly re-assigning the gaze paths to the stimulus paths (see Figure 6A). Concordantly, in 67% of cases it was possible to identify which stimulus path was viewed on a given trial from the gaze path recorded during that trial, by selecting among all stimulus paths the one with the smallest gaze-to-stimulus distance. This percentage is much higher than chance level (1/60). As can be seen in Figure 6B, the gaze-to-stimulus distance changed across conditions (Chi-square statistic (5,60)=44.52,  $p<<0.001$ ; Friedman test). The pattern of changes across conditions was however different than the changes in percept: gaze-to-stimulus distances were longest for morph levels M4 and M5, longer than distances observed at 'leaf', M1 and 'fly' (Tukey-Kramer post-hoc tests). This pattern of changes was thus more similar to the one found for speed and position

changes across conditions than to changes in percept. Regression tests performed on the gaze-to-distance values revealed that dot speed explained almost 20 times more variance than stimulus condition and participant response combined (adjusted R-squared: combined model: 0.095, dot speed: 0.093, condition: 0.004, response: 0.001, see Figure 6C).

### Gaze-to-stimulus lags

Lag estimates obtained from cross-correlation analyses and displayed in Figure 6D revealed that participants' gaze clearly lagged behind the stimulus. 96% of lag values were positive (i.e. the gaze path lagged behind the stimulus), with a median at 366ms and quartile deviation of 108ms. Control lag values obtained by pairing gaze paths with stimulus paths of different trials showed no such tendencies (grey line in Figure 6D). Lag values did not change with stimulus condition (Chi-square (5,60)=7.33,  $p=0.197$  and Chi-square (5,60)=9.31,  $p=0.097$  for horizontal and vertical axes respectively). The high amount of 0 lags among both observed and control values is due to the method used to calculate the cross-correlation used and to the fact that stimulus and gaze path data have very similar levels of smoothness.

~ Please insert Figure 6 about here ~

## Discussion

The results from this experiment confirm our assumption that participants would tend to follow the stimulus with their gaze. Further, we found differences in the eye movement data across conditions: The distance between point of gaze and stimulus changed across conditions, with variations in stimulus speed explaining these changes better than stimulus condition and participant response we tested. Nevertheless, these results raise the question whether the changes in animacy percept across conditions were influenced by eye movements, and whether the changes in animacy percept could be observed without eye movements.

## Experiment 5: Animacy judgments without eye movements

This experiment was identical to Experiment 4 except that to avoid eye movements, participants were forced to fixate on the centre of the screen during the whole duration of each trial. The aim of this experiment was to assess whether animacy judgments would still gradually change as a function of morph level as was found in the previous experiment where eye movements were free.

## Methods

### Participants

Participants were the same as in Experiment 4. The data of 3 participants had to be excluded due to technical problems with the eye tracker.

### Stimuli, procedure and analysis

Stimuli, procedure and setup including eye tracking equipment were identical to Experiment 4, except for the following differences. Immediately after the fixation cross appeared, participants were given a 0.5 s grace period to establish fixation on the fixation cross, after which period the dot stimulus was shown and started to move. If after this time fixation deviated by more than  $2^\circ$  from the fixation cross, the trial was aborted and repeated (gaze-contingent display). This procedure was made possible by streaming the eye position data online to MATLAB using custom code written in C++ by Mario Kleiner, MPI Biological Cybernetics, Tübingen, Germany. Analysis of the perceptual judgments was the same as in Experiment 2.

## Results and Discussion

As expected, a one-way, repeated-measures ANOVA revealed a strong effect of morph level on the animacy percept ( $F(5,55)=5.97$ ,  $p<0.001$ ). A linear trend was found:  $F(1,11)=15.1$ ,  $p<0.004$ . The data of 5 out of 12 participants could be significantly explained with a fitted logistic function. No participants showed percepts opposite to those expected. Response times did not differ between stimulus conditions (mean=1247ms, SEM=78ms,  $F(5,55)=0.3$ ,  $p>0.9$ ). Data are presented together with those of Experiments 4 and 6 in Figures 7 (percept) and 8 (response times). Comparisons with the results of Experiments 4 and 6 will be reported in the Results section of Experiment 6.

## Experiment 6: Dual task

The aim of this experiment was to assess whether reducing the attentional resources assigned to the stimuli would influence the reported percepts of animacy, and whether dividing attentional resources had a similar effect to suppressing eye movements. To this effect, we asked participants to perform a detection task requiring them to fixate constantly at the centre of the screen in addition to watching the moving dot stimulus and making the animacy decision at the end of the trial. This added to their effort as they were now required to perform two tasks simultaneously. Percepts were compared to those obtained from the same participants when they were free to move their eyes (Experiment 4) and when forced to fixate (Experiment 5).

## Methods

### Participants, stimuli, procedure, analysis

Participants, stimuli and procedure were identical to Experiment 4, except that no eye tracker was used, and that participants had to perform two simultaneous tasks, as follows. In addition to watching the moving dot stimulus and judge its animacy at the end of the trial, participants had to keep watching a central fixation spot and report luminance changes (grey  $\rightarrow$  white) by pressing a button as quickly as possible. Targets lasted 0.5 s and appeared randomly 1 to 3 times per trial. Animacy percepts and response times as well as target detection performance and response times were collected for analysis. Analysis of the animacy judgments data was as in Experiment 2, except that we added one factor in the ANOVA to allow direct comparison across Experiments 4, 5 and 6. The data of one participant was excluded due to partial data loss.

## Results

### Target detection task

Target detection performance was high (average hit rate was 92%) and there was no significant difference between conditions in hit rate ( $F(5,65)=1.82$ ,  $p>0.12$ ; one-way, repeated-measures ANOVA) and response times ( $F(5,65)=2.00$ ,  $p>0.09$ ; same ANOVA).

### Animacy responses in Experiment 6

A one-way, repeated-measures ANOVA computed on the data of Experiment 6 revealed a strong effect of morph level on the animacy percept ( $F(5,65)=6.11$ ,  $p<0.001$ ). A linear trend was found:  $F(1,13)=15.12$ ,  $p<0.003$ . The data of 6 out of 14 participants could be significantly explained with a fitted cumulative gaussian function. No participants showed percepts opposite to those expected. Response times did not differ between stimulus conditions (mean=1770ms, SEM=98ms,  $F(5,65)=1.1$ ,  $p>0.3$ ).

### Animacy percept across Experiments 4, 5 and 6

Figure 7 shows the proportion of “animate” responses obtained in Experiments 4, 5 and 6. The data were similar across Experiments 4 and 5, although they appear somewhat more noisy in Experiment 6. This increased noise in Experiment 6 leads to a shallower slope of the fitted function. In addition, the amplitude of the percept changes observed across conditions decreased across experiments: it was greatest in Experiment 6, followed by Experiment 5, then Experiment 4. A two-way, repeated-measures ANOVA with factors ‘condition’ (=morph level) and ‘experiment’ revealed as expected a highly significant effect of morph level on the animacy responses, but no effect of experiment or interaction between morph level and experiment (morph level:  $F(5,70)=15.36$ ,  $p<0.001$ , effects of experiment and

interaction:  $p > 0.3$ ). The amount of variance in the individual data explained by the fitted psychometric functions as well as the parameters of the functions did not change across experiments: one-way, repeated-measures ANOVA on the  $r$ -squared values of the fits, the PSEs and JNDs, and chi-squared tests comparing the number of participants with significant fits revealed no effect of experiment (all  $p > 0.26$ ). However, response times (Figure 8) showed a significant change across experiments with longer response times in Experiment 6, but no effect of morph level or interaction between experiment and morph level (same ANOVA design as used to analyze the judgments, effect of experiment:  $F(2,10) = 7.84$ ,  $p < 0.003$ , all other effects & interactions NS).

~ Please insert Figure 7 about here ~

~ Please insert Figure 8 about here ~

## Discussion

Comparing the results of Experiments 4 and 5 revealed that forcing participants to fixate the centre of the screen rather than letting them freely move their eyes tended to reduce slightly the amplitude of the changes in percept evoked by the stimuli. While there were no directly measurable effects on the reported animacy percepts, the data were more noisy. Comparing the results of Experiments 4 and 6 revealed that reducing the attentional resources available for the animacy judgments by having participants perform a central change detection task led to an increase in response times. This suggests that participants needed more time to make up their mind about how animate the stimulus appeared after having spent time concentrating on the central change detection task. When comparing across Experiments 5 and 6, it appears that animacy judgments were even more noisy in Experiment 6 than in Experiment 5. Overall, the results of Experiments 4-6 suggest that eye movements are not strictly necessary for the stimuli to evoke the percept, nor is constant full attention on the moving dot. Best performance is however observed with full attention and unconstrained eye movements.

## General discussion

We report a new parametric stimulus in which a single isolated dot evokes a graded change in the percept of animacy only through its motion, with minimal context information, by mimicking the movements of naturally occurring stimuli. We manipulated the dot's speed and direction changes over time to evoke gradual changes in the impression of self-propelledness, one of the critical factors contributing to the percept of animacy. The gradual chang-

es in self-propelledness evoked a gradual change in the percept of animacy. In our series of six experiments we report the following: (a) many participants spontaneously described our stimuli as representing flying insects and used this percept to judge their animacy, suggesting that our stimuli tap into representations of naturally-occurring moving objects; (b) our manipulation evoked the motions we attempted to simulate adequately for a majority (69%) of participants; (c) these perceptual changes could be obtained using a yes/no task with just the two most extreme stimuli or with six different levels to yield a psychometric function; (d) asking participants to give a free word-based description to the stimuli revealed similar changes in percept; (e) participants tended to follow the stimulus with their gaze if left free to do so, but these eye movements were not strictly necessary to obtain the changes in percept; (f) reducing attentional resources by asking participants to perform an additional task unrelated to the stimuli during animacy judgments reduced the changes in percept but did not eliminate them. This stimulus thus allows investigating which factors influence the detection of animate agents through their motion, and to study the neural correlates involved in this process.

As reported in the Results of Experiments 1 and 2, some participants (about 9%) reported the opposite percept to what we had predicted: to them, the 'fly' stimulus appeared less animate than the 'leaf' stimulus. Post-experiment debriefing revealed that many of these participants used different strategies than the other participants. They argued that rapid speed and direction changes were in general more frequent in animals, and because of the wind effects we introduced, such changes happened more frequently at the 'fly' end of the continuum than at the 'leaf' end. This suggests that these participants used a particular cognitive strategy or heuristic in order to solve the task, rather than simply relying on the percept they immediately experienced when watching the stimuli. Unfortunately, this strategy was at odds with the design ideas behind our stimuli, and led those participants to report the opposite percepts to what was expected. In our view, the consequence of this finding is that our stimuli, while certainly useful already in the way we described them in the current paper, could be perfected such as to work with more participants. Alternatively, one could try to minimize strategy-taking by explicitly emphasizing in the instructions that participants should report the first percept that comes to mind rather than "thinking too much". While this might lead to more noise in the data, it could reduce systematic misinterpretation of our stimuli. Interestingly, no observer systematically reported such unexpected percepts in Experiments 3 to 6. It is possible that this is due to the number of participants tested: In Experiments 3, 4, 5 and 6, we only tested 14 participants, so given the incidence of opposite percepts of 9% observed in Experiments 1 and 2, we would expect only 1 or 2 participants to report opposite percepts. The absence of this finding could be due to chance. Alternatively, it could be due to differences between experiments: In Exper-

iments 5 and 6, the animacy task was more difficult as participants were forced to fixate / divide their attention. This led to percept changes of reduced amplitude and to more noisy responses, which thus also decreases the likelihood of observing percepts opposite to what was expected. If, despite some changes to our stimuli, these unexpected opposite percepts were revealed to be genuine perceptual differences between participants, one may be able to use these differences advantageously in future neuroimaging experiments attempting to identify neural structures involved in making animacy decisions. For example, in a between-subjects design in which some participants perceived the stimuli as we intended them to and some perceived them in the opposite manner, one could better dissociate the neural correlates of making the decisions from the neural responses to the actual stimulus by capitalising on these individual differences, compared to a situation where all participants had the same percepts. However, pursuing this consideration goes beyond the scope of the current paper.

A convincing minimal stimulus for displaying moving humans and other articulated animals is the point-light walker display pioneered by Johansson (Johansson, 1973) and widely studied since (Blake & Shiffrar, 2007). This stimulus is reliably recognized because it triggers representations of humans or other articulated animals, and it has thus been widely used to study how we detect and process biological motion. However, for this stimulus to be perceived, integration of form and motion is necessary (Casile & Giese, 2005; Giese & Poggio, 2003; Lange & Lappe, 2006). As we can also perceive a single isolated object as an animate agent, it would be useful to build a stimulus capable of evoking an animacy percept on its own with a minimum of prior context, like the point-light walker. This was the (overly ambitious) aim of the current study. While the animacy percept evoked by our stimulus is certainly not as strong nor as immediate as the percept evoked by a point-light walker display, we believe it is a promising attempt.

We believe that in most natural situations in which humans are confronted with isolated, non-articulated, potentially animate agents, the visual system integrates information over time to gather signs of self-propelledness or goal-directedness contained in the motion of the object. This would allow to identify flying insects and to distinguish them from small objects moved by external forces such as gravity or wind, which are examples of simple moving objects that can easily be categorized into animate and inanimate simply on the basis of their motion (Leslie, 1982). We tried to simulate such stimuli that can occur in real life, in order to draw upon everyday experience of our participants and thus increase the likelihood of tapping into the processes normally involved in attributing animacy to moving objects. In order to induce such an integration of motion information over time to make their animacy judgments, we kept the distributions of speed, acceleration and position as constant as possible across conditions. This prohibited participants from basing their decisions on simple, low-level visual cues. Also, we generated new trajectories

on every trial, to avoid statistical learning of particular trajectories. Previous studies have reported that prior information and concepts influence the perception of animacy (Gelman et al., 1995; Opfer, 2002; Santos, David, Bente, & Vogeley, 2008). However, we strived to make the task as perceptual as possible, by minimizing the background information required for the stimuli to evoke the percepts we wanted to simulate. Given that many participants spontaneously reported thinking about insects or objects pushed around by the wind, we believe to have created reasonable approximations of these natural stimuli. The fact that some participants did not experience the changes in percept we attempted to induce (some even experienced the opposite percept) suggests that not all participants had the same representations. This was confirmed by post-experiment reports: for example, one participant who grew up in an environment with many different flying insects mentioned that all stimuli looked like animate beings as they evoked different kinds of flying insects. Overall, we believe that our stimuli evoked representations of naturally occurring living and non living objects solely through their motion.

While we relied on varying the amount of self-propelledness induced by our stimuli, we are aware that there are other strong cues to the perception of animacy. For example, signs of goal-directed motion have been seen by some researchers as more important than self-propelledness (Opfer, 2002). In general, signs of minimal mental capacity including intentional behaviour lead to increased percepts of animacy (Tremoulet & Feldman, 2006). Other cues have been reported in displays involving one object and a context or in displays of several interacting objects. The visual context of a moving object can augment or suppress animacy impressions, by giving the impression that the moving object is reacting to changes in the environment through spatio-temporal contingencies in its movements (Tremoulet & Feldman, 2006). For example, time delays in the interactions between objects induce an impression of animacy, particularly when associated with proximity between the objects, by evoking the impression of a communication between the objects (Santos et al., 2008). Recently, Tao Gao and collaborators have reported studies using relative motion cues in multi-objects displays and achieved impressive animacy and intentionality percepts, including interesting consequences of perceiving animacy (Gao & Scholl, 2011; Gao, McCarthy, & Scholl, 2010; Gao, Newman, & Scholl, 2009). Such complex cues could not be used in our study, as we constrained ourselves to only one object. Having a single-dot stimulus that can evoke a parametric percept of animacy on its own opens the possibility to compare the detection of animacy in single-dot stimuli with detection of animacy in multi-dot stimuli. Further, it allows comparing animacy detection with detection of social agency and social interactions between abstract stimuli.

Finally, we would like to note that the stimuli we report here do not represent the first attempt to create motion stimuli that can evoke parametric percepts of animacy.



Previous work includes displays in which two dots interact with each other through chasing or in other ways (Gao & Scholl, 2011; Mcaleer & Pollick, 2008; Santos et al., 2008; Schultz, Friston, O'Doherty, Wolpert, & Frith, 2005; Tremoulet & Feldman, 2000; 2006). However, as previously mentioned, we are not aware of a parametric stimulus consisting of a single dot capable of evoking graded changes in the percept of animacy by mimicking the motion of naturally occurring animate and inanimate objects.

## Appendix A

Responses given in debriefing following Experiment 1, in response to the question: "How did you decide if the object was animate or not" (Note: reports were given in German, reported here are translations made by the Authors)

Subject 1: "By imagining a suitable object (dead leaf, billiard or flipper ball) or a living being (fly, mosquito, fish) and using the uniformity of the movement."

Subject 2: "When the object often change direction, made small jittery movements and flew in loops, I considered it animate. For example, sometimes I thought about an insect and I decided 'animate', sometimes I thought about a person cleaning a window and decided inanimate"

Subject 3: "I tended to respond animate based on velocity (faster for animate), if the dots moved in circles, or if there was a lot of jitter. I responded inanimate when the dots moved very little, or had long durations of slow motion in the same direction followed by a sudden burst (wind)."

Subject 4: "Faster objects appeared more animate, objects that move towards the border of the screen appeared more animate, objects whose motion appeared 'chopped' and who changed speed appeared more animate"

Subject 5: "I decided it was animate if it looked like a fly or a mosquito, or a bird flying and diving. Not animate if it looked like a kid was drawing on a piece of paper."

Subject 6: "I decided animate if it looked like a flying insect, fly for example, or a bird diving and flying around in the sky. Animate mainly if appeared to be driven by its own force, not if moved by external force"

Subject 7: "animate if looks like fly and not if looks like leaf"

Subject 8: "animate if it makes many small tight turns and moves relatively fast, not if it makes large, slow 'sweeps'. Animate if looks like a fly, not if it moves like a leaf"

Subject 9: "I decided it was animate when I thought a fly or insect was present"

Subject 10: "I decided it was animate if it looked like a fly"

Subject 11: "could all be flies, but if speed has slow changes, it's not so animate, if the speed/direction changes are fast, it's animate."

Subject 12: "I thought of birds flying around, diving, doing turns... really hard, but I tried very hard."

Subject 13: "Animate ones move by themselves, dead ones are moved by external forces."

## Appendix B

Examples of verbal reports given in Experiment 3. (Note: reports were given in German, reported here are translations made by the Authors).

### **Clearly inanimate (animacy rating 1):**

"balloon rising in the sky"  
 "crazy dot"  
 "children's swing"  
 "plastic bag in the wind"  
 "leaf falling from a tree"  
 "leaf in a storm"  
 "snowflake falling and picked up again"  
 "kite pulled by the wind"  
 "dust circling around"  
 "bouncing SuperBall"  
 "volleyball bounced between players"  
 "paper airplane flying"  
 "key attached to key-ring twirled around"  
 "billiard or flipper ball bounced around"

### **Clearly animate (animacy rating 7):**

"bee looking for flowers"  
 "insect wondering where to go"  
 "moth circling a lamp"  
 "duck landing in lake"  
 "butterfly in the wind"  
 "squirrel on a tree"  
 "dog playing"  
 "hectic bird"  
 "bug on the window"  
 "thing panicking to find the exit"  
 "chicken on a ladder"  
 "firefly"  
 "butterfly"  
 "person cleaning a window"

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## Figure legends

Figure 1. Examples of stimulus direction and speed over time, as a function of  $\beta$ . At  $\beta = 0$  (the “leaf” end of the continuum), changes in direction (A) are overall smooth but have several sharp “steps” accompanied by marked changes in speed (C), which together reflect a particular acceleration profile of (our implementation of wind bursts). At  $\beta = 1$  (the “fly”), changes in direction (B) are more frequent, mostly smaller and less sustained, and less frequently accompanied by changes in speed (D). The interplay between changes in direction and speed led to more or less strong percepts of self-propelledness and thus animacy, depending on the value of  $\beta$ .

Figure 2. Results of Experiment 1: Animacy percepts evoked by extreme stimuli. Participants judged the ‘fly’ stimuli as more animate than the ‘leaf’ stimuli. 38 of 56 individual participants showed the same effect. Data indicate the proportion of ‘Animate’ responses given to each stimulus type and are shown pooled over all participants (left) and only over those with significant differences in animacy ratings between ‘leaf’ and ‘fly’ (right). Error bars represent the standard error of the mean over participants.

Figure 3: Stimulus description and statistics. The stimulus consisted in a single dot moving on a blank background. (A) Names of the simulated motions: ‘leaf’ and ‘fly’ and the intermediary morphs (M2 to M5). (B) Graphical representation of the simulated motion. (C) Magnitude of the parameter ‘beta’ controlling the dot movement (see Methods). (D) Example dot motion trajectories for one trial per stimulus type, illustrating their diversity and the lack of indication about the simulated motion: the dot only appears animate when moving. Each trial of each condition had a unique trajectory. (E – I) Statistics about the stimulus, computed over >600 trials, showing distribution of horizontal and vertical position of the dot on the screen (E and F, respectively), speed (G), acceleration (H) and movement direction (I). The box covers lower to upper quartile values, the median is indicated by the middle horizontal line. The vertical grey lines extend from each end of the box to the most extreme data value within 1.5 times the inter-quartile range of the box.

Figure 4. Results of Experiment 2: Animacy percepts evoked by stimuli with 6 morph levels. Results from the yes-no animacy judgment task with six stimulus conditions fitted by a psychometric function (fits were significant for the group-average data and the individual data of 40 of 56 participants). Circles and error bars indicate mean and standard errors of the mean over participants of the average proportion of ‘Animate’ responses given to stimuli of each morph level. Data are shown pooled over all participants (dark grey) and pooled over the participants whose individual data could be significantly explained by a fitted psychometric function (light grey). Error bars represent the standard error of the mean over participants.

Figure 5. Results of Experiment 3: Ratings of verbal reports on 6 morph levels. Verbal reports show that stimuli appear increasingly animate when stimuli are parametrically morphed from ‘leaf’ to ‘fly’. Example responses are shown in Appendix B. Boxplots show ratings of the verbal reports given by the participants (as in Figure 3, with notches showing robust estimates of the uncertainty about the medians). Median ratings mostly lay in the upper half of the response range, suggesting that all stimuli appeared relatively animate. Boxplot conventions are as in Figure 3; in addition, notches represent a robust estimate of the uncertainty about the means for box-to-box comparison.

Figure 6. Results of Experiment 4: Gaze behaviour. Statistics of eye gaze measures. (A) Distribution of distances between stimulus and point of regard: distances observed (black line) are much smaller than a control distribution (grey line) of distances between the gaze path acquired in a given trial and the stimulus paths of all the other trials. (B) Distances between stimulus and point of regard significantly differed across conditions. (C) Linear regression tests using dot speed, stimulus condition and participant response as explanatory variables revealed that dot speed had by far the greatest explanatory power on the variation in the distance between stimulus and gaze position. (D) Lag estimates from cross-correlation between stimulus position and eye gaze (black line) clearly indicate that gaze lagged behind the stimulus (median = 366ms). Control lag values obtained by pairing gaze paths with stimulus paths of different trials showed no such tendencies (grey line). Error bars represent standard error of the mean except for panel B, where boxplot conventions are as in Figure 3.

Figure 7. Results of Experiments 4-6: effects of constraining eye movements and manipulating attention on animacy judgments. Animacy judgments obtained in Experiments 4, 5 and 6 could be significantly explained by a fitted psychometric function. Although no significant difference between experiments could be found, the best performance (least noisy changes in percept, greatest amplitude of changes in percept) was obtained in Experiment 4, in which participants were free to move their eyes, and the worst performance was obtained in Experiment 6, in which participants had to perform an additional task during stimulus presentation. Symbols and error bars indicate mean and standard errors of the mean over participants of the average proportion of ‘Animate’ responses given to stimuli of each morph level.

Figure 8. Results of Experiments 4-6: Response times of Yes-no task on stimuli with 6 morph levels. The time needed to judge the animacy of the stimulus changed significantly across Experiments 4, 5 and 6, with the longest response times obtained in Experiment 6. Symbols and error bars indicate mean and standard errors of the mean over participants of the average response time needed to judge the animacy of the stimuli of each morph level.

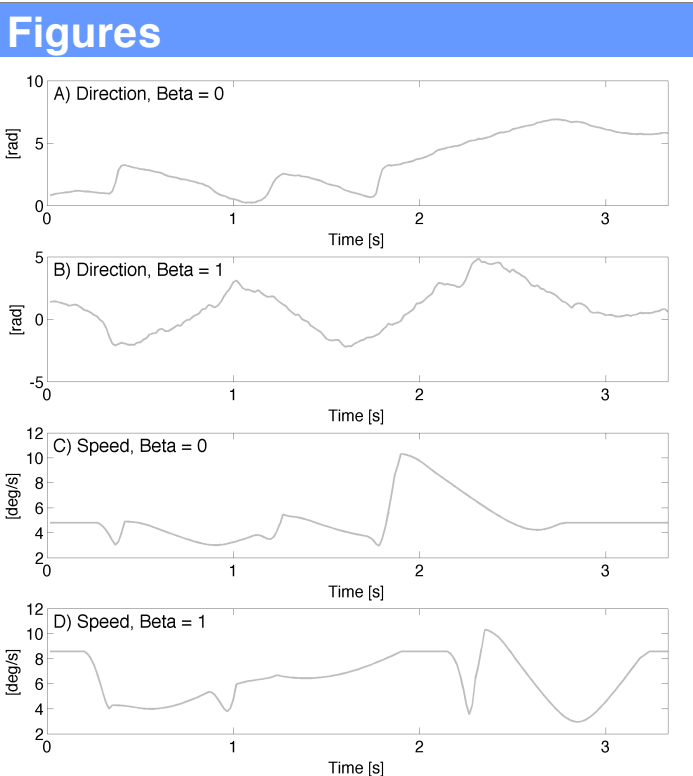


Figure 1

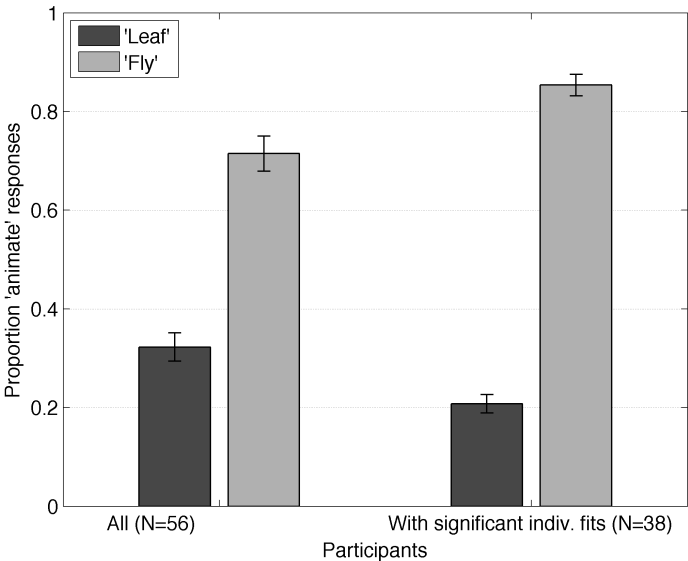


Figure 2

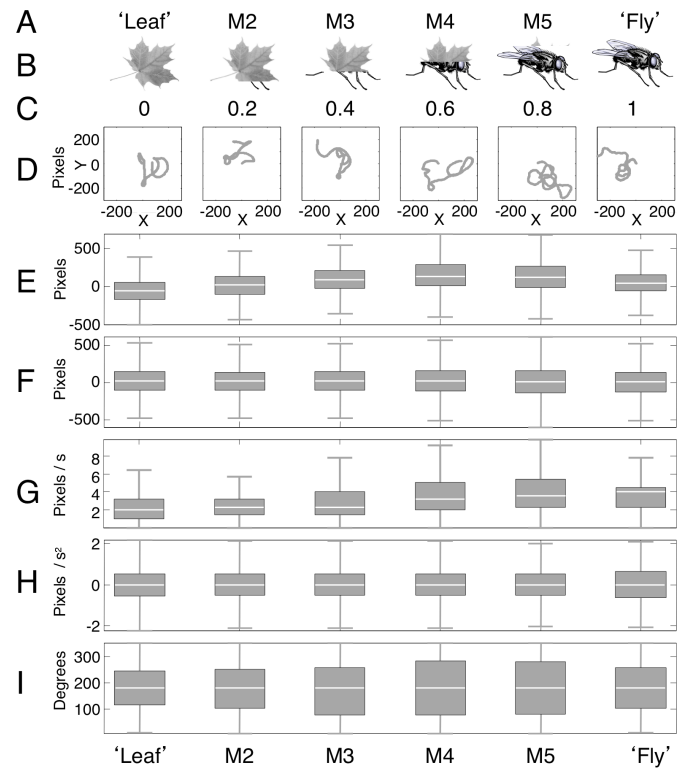


Figure 3

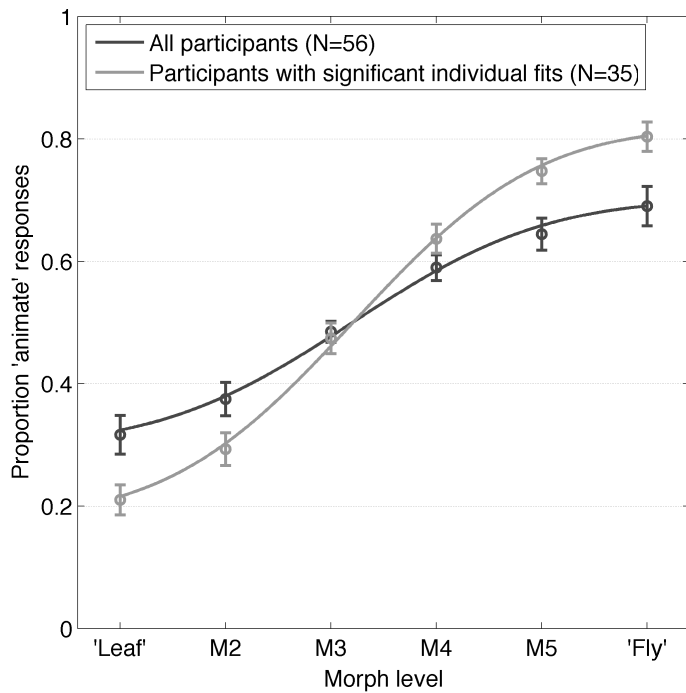


Figure 4

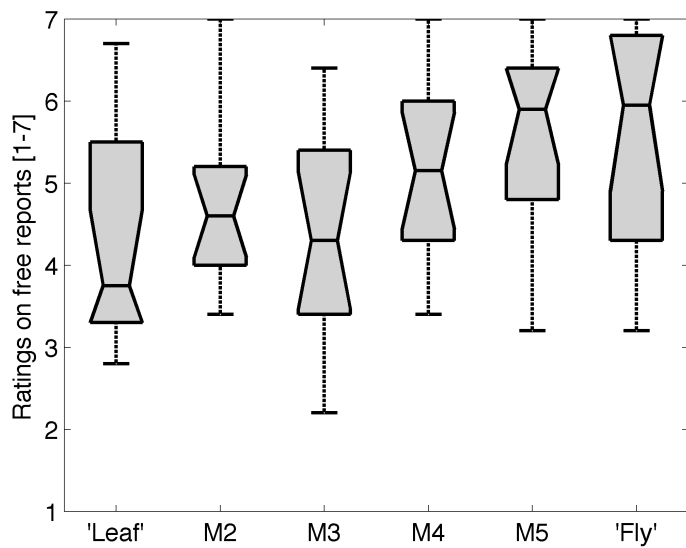


Figure 5

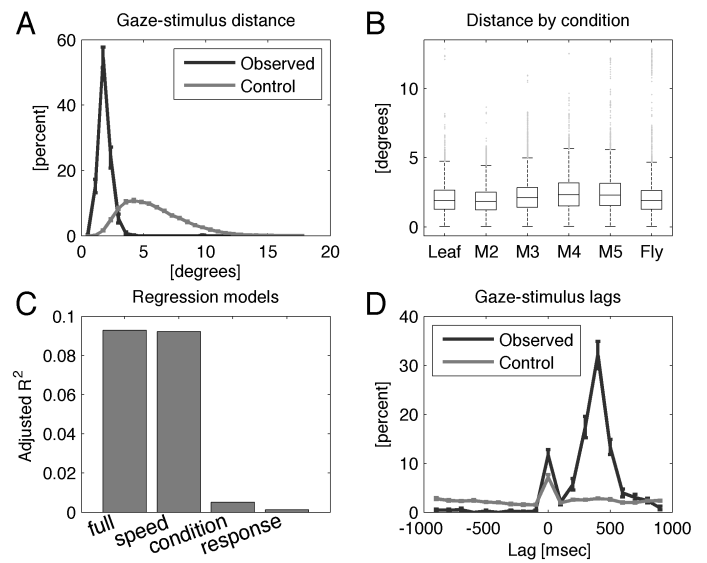


Figure 6

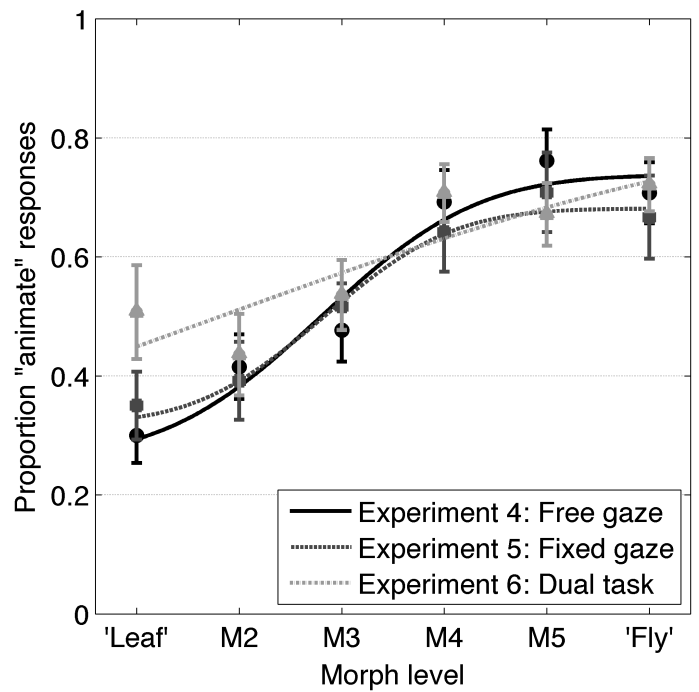


Figure 7



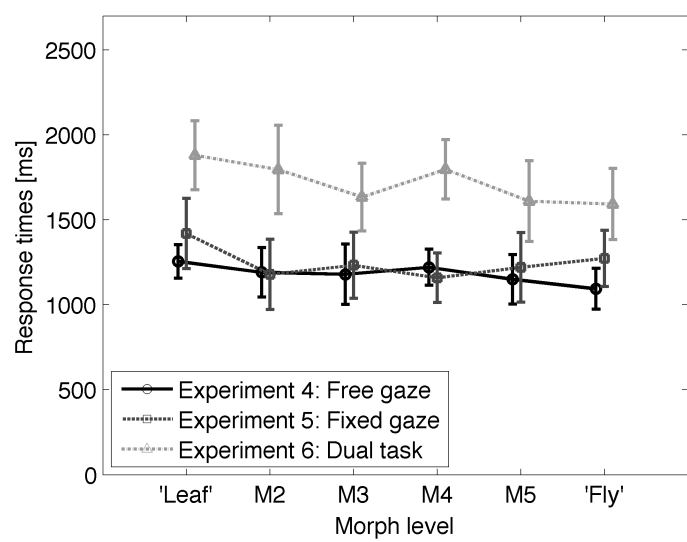


Figure 8